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PHASE SHIFTERS, INTERROGATORS, METHODS OF
SHIFTING A PHASE ANGLE OF A SIGNAL, AND METHODS
OF OPERATING AN INTERROGATOR

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1 PHASE SHIFTERS, INTERROGATORS, METHODS OF SHIFTING A
2 PHASE ANGLE OF A SIGNAL, AND METHODS OF OPERATING
AN INTERROGATOR

3 TECHNICAL FIELD

4 The present invention relates to phase shifters, interrogators,
5 methods of shifting a phase angle of a signal, and methods of operating
6 an interrogator.

7
8 BACKGROUND OF THE INVENTION

9 Electronic identification devices, such as radio frequency identification
10 devices (RFIDs), are known in the art. Such devices are typically used
11 for inventory tracking. As large numbers of objects are moved in
12 inventory, product manufacturing, and merchandising operations, there is a
13 continuous challenge to accurately monitor the location and flow of objects.
14 Additionally, there is a continuing goal to determine the location of objects
15 in an inexpensive and streamlined manner. One way of tracking objects
16 is with an electronic identification system.

17 One presently available electronic identification system utilizes a
18 magnetic coupling system. In some cases, an identification device may be
19 provided with a unique identification code in order to distinguish between
20 a number of different devices. Typically, the devices are entirely passive
21 (have no power supply), which results in a small and portable package.
22 However, such identification systems are only capable of operation over
23 a relatively short range, limited by the size of a magnetic field used to
24 supply power to the devices and to communicate with the devices.

1 Another type of wireless electronic identification system is an active
2 wireless electronic identification system. Attention is directed towards
3 commonly assigned U.S. Patent Application Serial No. 08/705,043, filed
4 August 29, 1996, and incorporated herein by reference, which describes
5 such active systems in detail. One such system is sold by Micron
6 Communications Inc., 3176 S. Denver Way, Boise, Idaho 83705 under the
7 trademark Microstamp Engine (TM).

8 These systems include integrated circuit devices which include an
9 active transponder and are intended to be affixed to an object to be
10 monitored. The devices are capable of receiving and processing
11 instructions transmitted by an interrogator. A device receives the
12 instruction, if within range, then processes the instruction and transmits a
13 response, if appropriate. The interrogation signal and the responsive signal
14 are typically radio-frequency (RF) signals produced by an RF transmitter
15 circuit.

16 Because active devices have their own power sources, they do not
17 need to be in close proximity to an interrogator or reader to receive
18 power via magnetic coupling. Therefore, active transponder devices tend
19 to be more suitable for applications requiring tracking of a tagged device
20 that may not be in close proximity to an interrogator. For example,
21 active transponder devices tend to be more suitable for inventory control
22 or tracking.

23 The active transponder is capable of using backscatter
24 communication techniques in responding to an interrogator. The

1 interrogator outputs a polling signal followed by a continuous
2 wave (CW) signal. The integrated circuit devices are configured to
3 modulate the continuous wave signal in backscatter communication
4 configurations. This modulation typically includes selective reflection of
5 the continuous wave signal. The reflected continuous wave signal
6 includes the reply message from the remote devices which is
7 demodulated by the interrogator.

8 Certain drawbacks have been identified with the use of backscatter
9 communication techniques. For example, the transmission of the
10 continuous wave signal using the interrogator can desensitize the receiver
11 of the interrogator during reception thereby of reply signals from
12 associated remote devices. In particular, some of the continuous wave
13 signal tends to bleed through to the received reply messages. Such
14 results in degradation of wireless communications.

15 Systems have been provided which improve wireless communications
16 without the drawbacks associated with conventional devices. Variable
17 phase shifters can be used in such systems. However, conventional
18 variable phase shifters are typically very expensive and typically only
19 operate within a certain specified range, (e.g., 0 to 180 degrees).

20 21 SUMMARY OF THE INVENTION

22 The present invention includes variable phase shifters, interrogators,
23 methods of shifting a phase angle of a signal, and methods of operating
24 an interrogator.

1 It is desired to reduce power within a modulated return link
2 continuous wave signal of a coherent backscatter communication system
3 including an interrogator and at least one remote communication device.
4 Exemplary remote communication devices include remote intelligent
5 communication devices and radio frequency identification devices (RFID)
6 of electronic identification systems.

7 An exemplary interrogator comprises a coherent interrogator
8 configured to provide backscatter communications. More specifically, the
9 interrogator is configured to output a forward link communication and
10 a wireless continuous wave signal using a transmitter. The interrogator
11 is also configured to output a local continuous wave signal to a receiver
12 of the interrogator following transmission of the forward link
13 communication. Provision of the local signal enables coherent operation
14 of the interrogator. The interrogator is operable to receive return link
15 communications from at least one remote communication device
16 responsive to transmission of the forward link wireless communication.

17 The interrogator preferably includes a receiver operable to reduce
18 the amplitude of a carrier signal of the return link communication. For
19 backscatter communications, the remote communication device is
20 configured to modulate the continuous wave signal providing a carrier
21 component and side band components. The receiver of the interrogator
22 is preferably configured to reduce the amplitude of the carrier
23 component while maintaining the amplitudes of the side band
24 components.

1 Variable phase shifters are disclosed to adjust the phase angle of
2 the local continuous wave signal using a determined phase shift angle
3 to reduce bleed through. The determined phase shift angle may be
4 varied during operation of the interrogator. According to one aspect
5 of the present invention, a phase shifter includes a power divider
6 configured to provide plural quadrature components of an input signal,
7 such as the local continuous wave signal. Plural mixers are provided
8 to scale the quadrature components using the phase shift angle. A
9 second power divider is provided to combine the scaled quadrature
10 components to shift the phase angle of the input signal by the phase
11 shift angle.

12 Methods of certain aspects of the present invention provide
13 shifting of a phase angle of an input signal according to a phase shift
14 angle. A method of one aspect includes providing the input signal into
15 plural components. Thereafter, the components are scaled using the
16 phase shift angle and combined to shift the phase angle of the input
17 signal by the phase shift angle.

18 19 BRIEF DESCRIPTION OF THE DRAWINGS

20 Preferred embodiments of the invention are described below with
21 reference to the following accompanying drawings.

22 Fig. 1 is a block diagram of an exemplary communication system.

23 Fig. 2 is a front view of a wireless remote communication device
24 according to one embodiment.

1 Fig. 3 is a front view of an employee badge according to another
2 embodiment.

3 Fig. 4 is a functional block diagram of an exemplary transponder
4 included in the remote communication device of Fig. 2.

5 Fig. 5 is a functional block diagram of an exemplary interrogator
6 of the communication system.

7 Fig. 6 is a functional block diagram of an RF section of the
8 interrogator.

9 Fig. 7 is a functional block diagram of an adaptive canceler of
10 the RF section.

11 Fig. 8 is a schematic diagram of amplitude detectors and an
12 amplitude adjuster according to one adaptive canceler configuration.

13 Fig. 9 is a graphical illustration of a summed return link
14 communication outputted from the adaptive canceler.

15 Fig. 10 is a schematic diagram illustrating one configuration of an
16 amplitude detector and a phase adjuster of the adaptive canceler.

17 Fig. 11 is a graphical illustration of a received return link
18 communication.

19 Fig. 12 is a graphical illustration of a summed return link
20 communication.

21 Fig. 13 is a diagrammatic representation of a forward link
22 communication and a return link communication within the
23 communication system.
24

1 Fig. 14 is a circuit schematic showing a variable phase shifter
2 used in the adaptive canceler, in one embodiment, and which also has
3 other uses.

4 Fig. 15 is a graphical illustration of a relationship between I
5 and Q components in the variable phase shifter of Fig. 14.

6 7 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

8 This disclosure of the invention is submitted in furtherance of the
9 constitutional purposes of the U.S. Patent Laws "to promote the
10 progress of science and useful arts" (Article 1, Section 8).

11 Fig. 1 illustrates a wireless communication system 10 embodying
12 the invention. Communication system 10 comprises an electronic
13 identification system in the embodiment described herein. Further, the
14 described communication system 10 is configured for backscatter
15 communications as described in detail below. Other communication
16 protocols are utilized in other embodiments.

17 The depicted communication system 10 includes at least one
18 electronic wireless remote communication device 12 and an
19 interrogator 26. Radio frequency communications can occur intermediate
20 remote communication devices 12 and interrogator 26 for use in
21 identification systems and product monitoring systems as exemplary
22 applications.

23 Devices 12 include radio frequency identification devices (RFID)
24 or remote intelligent communication (RIC) devices in the embodiments

1 described herein. Exemplary devices 12 are disclosed in U.S. Patent
2 Application Serial No. 08/705,043, filed August 29, 1996. Plural wireless
3 remote communication devices 12 typically communicate with
4 interrogator 26 although only one such device 12 is illustrated in Fig. 1.

5 In one embodiment, wireless remote communication device 12
6 comprises a wireless identification device such as the MicroStamp (TM)
7 integrated circuit available from Micron Communications, Inc., 3176 S.
8 Denver Way, Boise, Idaho 83705. Such a remote communication
9 device 12 can be referred to as a tag or card as illustrated and
10 described below.

11 Although multiple communication devices 12 can be employed in
12 communication system 10, there is typically no communication between
13 multiple devices 12. Instead, the multiple communication devices 12
14 communicate with interrogator 26. Multiple communication devices 12
15 can be used in the same field of interrogator 26 (i.e., within the
16 communications range of interrogator 26). Similarly, multiple
17 interrogators 26 can be in proximity to one or more of devices 12.

18 The above described system 10 is advantageous over prior art
19 devices that utilize magnetic field effect systems because, with system 10,
20 a greater range can be achieved, and more information can be obtained
21 (instead of just identification information). As a result, such a
22 system 10 can be used, for example, to monitor large warehouse
23 inventories having many unique products needing individual discrimination
24

1 to determine the presence of particular items within a large lot of
2 tagged products.

3 Remote communication device 12 is configured to interface with
4 interrogator 26 using a wireless medium in one embodiment. More
5 specifically, communications intermediate communication device 12 and
6 interrogator 26 occur via an electromagnetic link, such as an RF link
7 (e.g., at microwave frequencies) in the described embodiment.
8 Interrogator 26 is configured to output forward link wireless
9 communications 27. Further, interrogator 26 is operable to receive reply
10 or return link wireless communications 29 from devices 12 responsive to
11 the outputting of forward link communication 27. In accordance with
12 the above, forward link communications and return link communications
13 comprise wireless signals, such as radio frequency signals, in the
14 described embodiment. Other forms of electromagnetic communication,
15 such as infrared, acoustic, etc. are possible.

16 Interrogator unit 26 includes a plurality of antennas X1, R1, as
17 well as transmitting and receiving circuitry, similar to that implemented
18 in devices 12. Antenna X1 comprises a transmit antenna and
19 antenna R1 comprises a receive antenna individually connected to
20 interrogator 26.

21 In operation, interrogator 26 transmits the interrogation command
22 or forward link communication signal 27 via antenna X1.
23 Communication device 12 is operable to receive the incoming forward
24 link signal. Upon receiving signal 27, communication device 12 is

1 operable to respond by communicating the responsive reply or return
2 link communication signal 29. Communications of system 10 are
3 described in greater detail below.

4 In one embodiment, responsive signal 29 is encoded with
5 information that uniquely identifies, or labels the particular
6 device 12 that is transmitting, so as to identify any object, animal, or
7 person with which communication device 12 is associated.

8 More specifically, remote device 12 is configured to output an
9 identification signal within reply link communication 29 responsive to
10 receiving forward link wireless communication 27. Interrogator 26 is
11 configured to receive and recognize the identification signal within the
12 return or reply link communication 29. The identification signal can be
13 utilized to identify the particular transmitting communication device 12.

14 Referring to Fig. 2, one embodiment of remote communication
15 device 12 is illustrated. The depicted communication device 12 includes
16 a transponder 16 having a receiver and a transmitter as described
17 below. Communication device 12 further includes a power source 18
18 connected to transponder 16 to supply operational power to
19 transponder 16. In the illustrated embodiment, transponder 16 is in the
20 form of an integrated circuit 19. However, in alternative embodiments,
21 all of the circuitry of transponder 16 is not necessarily all included in
22 integrated circuit 19.

23 Power source 18 is a thin film battery in the illustrated
24 embodiment, however, in alternative embodiments, other forms of power

1 sources can be employed. If the power source 18 is a battery, the
2 battery can take any suitable form. Preferably, the battery type will be
3 selected depending on weight, size, and life requirements for a particular
4 application. In one embodiment, battery 18 is a thin profile button-type
5 cell forming a small, thin energy cell more commonly utilized in watches
6 and small electronic devices requiring a thin profile. A conventional
7 button-type cell has a pair of electrodes, an anode formed by one face
8 and a cathode formed by an opposite face. In an alternative
9 embodiment, the battery comprises a series connected pair of button
10 type cells.

11 Communication device 12 further includes at least one antenna
12 connected to transponder 16 for wireless transmission and reception.
13 In the illustrated embodiment, communication device 12 includes at least
14 one receive antenna 44 connected to transponder 16 for radio frequency
15 reception by transponder 16, and at least one transmit antenna 46
16 connected to transponder 16 for radio frequency transmission by
17 transponder 16. The described receive antenna 44 comprises a loop
18 antenna and the transmit antenna 46 comprises a dipole antenna.

19 Communication device 12 can be included in any appropriate
20 housing or packaging. Fig. 2 shows but one example of a housing in
21 the form of a miniature housing 11 encasing device 12 to define a tag
22 which can be supported by an object (e.g., hung from an object, affixed
23 to an object, etc.).
24

1 Referring to Fig. 3, an alternative housing is illustrated. Fig. 3
2 shows a housing in the form of a card 13. Card 13 preferably
3 comprises plastic or other suitable material. Plastic card 13 houses
4 communication device 12 to define an employee identification
5 badge including the communication device 12. In one embodiment, the
6 front face of card 13 has visual identification features such as an
7 employee photograph or a fingerprint in addition to identifying text.

8 Although two particular types of housings have been disclosed, the
9 communication device 12 can be included in any appropriate housing.
10 Communication device 12 is preferably of a small size that lends itself
11 to applications employing small housings, such as cards, miniature tags,
12 etc. Larger housings can also be employed. The communication
13 device 12, provided in any appropriate housing, can be supported from
14 or attached to an object in any desired manner.

15 Fig. 4 is a high level circuit schematic of transponder 16 utilized
16 in the devices of Figs. 1-3. In the embodiment shown in Fig. 4,
17 transponder 16 is implemented within monolithic integrated circuit 19.
18 In the illustrated embodiment, integrated circuit 19 comprises a single
19 die, having a size of 209 x 116 mils², including a receiver 30,
20 transmitter 32, microcontroller or microprocessor 34, a wake up timer
21 and logic circuit 36, a clock recovery and data recovery circuit 38, and
22 a bias voltage and current generator 42. Integrated circuit 19
23 preferably comprises a small outline integrated circuit (SOIC) package.
24

1 Receiver 30 and transmitter 32 comprise wireless communication circuitry
2 configured to communicate wireless signals.

3 In one embodiment, communication devices 12 switch between a
4 "sleep" mode of operation, and higher power modes to conserve energy
5 and extend battery life during periods of time where no interrogation
6 signal 27 is received by devices 12, using the wake up timer and logic
7 circuitry 36.

8 In one embodiment, a spread spectrum processing circuit 40 is
9 included in transponder 16. In this embodiment, signals transmitted and
10 received by interrogator 26 and signals transmitted and received by
11 communication device 12 are modulated spread spectrum signals. Many
12 modulation techniques minimize required transmission bandwidth.
13 However, the spread spectrum modulation techniques employed in the
14 illustrated embodiment require a transmission bandwidth that is up to
15 several orders of magnitude greater than the minimum required signal
16 bandwidth. Although spread spectrum modulation techniques are
17 bandwidth inefficient in single user applications, they are advantageous
18 where there are multiple users, as is the case with the preferred radio
19 frequency identification communication system 10 of the present
20 invention.

21 The spread spectrum modulation technique of the illustrated
22 embodiment is advantageous because the interrogator signal can be
23 distinguished from other signals (e.g., radar, microwave ovens, etc.)
24 operating at the same frequency. The spread spectrum signals

1 transmitted by communication device 12 and interrogator 26 are pseudo
2 random and have noise-like properties when compared with the digital
3 command or reply. The illustrated embodiment employs direct sequence
4 spread spectrum (DSSS) modulation.

5 In operation, interrogator 26 sends out a command that is spread
6 around a certain center frequency (e.g, 2.44 GHz). After the
7 interrogator transmits the command, and is expecting a response, the
8 interrogator switches to a continuous wave (CW) mode for backscatter
9 communications. In the continuous wave mode, interrogator 26 does not
10 transmit any information. Instead, the interrogator just transmits a
11 radio frequency continuous wave signal. In the described embodiment,
12 the continuous wave signal comprises a radio frequency 2.44 GHz carrier
13 signal. In other words, the continuous wave signal transmitted by
14 interrogator 26 is not modulated. After communication device 12
15 receives the forward link communication from interrogator 26,
16 communication device 12 processes the command.

17 If communication device 12 is operating in a backscatter mode,
18 device 12 modulates the continuous wave signal providing a modulated
19 continuous wave signal to communicate return link communication 29
20 responsive to reception of forward communication signal 27.
21 Communication device 12 may modulate the continuous wave signal
22 according to a subcarrier or modulation signal. Modulation by
23 device 12 comprises selective reflection of the continuous wave signal.
24 In particular, device 12 alternately reflects or does not reflect the

1 continuous wave signal from the interrogator to send its reply. For
2 example, in the illustrated embodiment, two halves of a dipole antenna
3 are either shorted together or isolated from each other to send a reply.
4 Alternatively, communication device 12 can communicate in an active
5 mode.

6 The modulated continuous wave signal communicated from
7 device 12 comprises a carrier component and plural side band
8 components about the carrier component resulting from the modulation.
9 More specifically, the modulated continuous wave signal output from
10 device 12 includes a radio frequency continuous wave signal having a
11 first frequency (2.44 GHz), also referred to as a carrier component, and
12 a subcarrier modulation signal having a different frequency
13 (e.g., 600 kHz) and which provides the side band components. In
14 particular, the side band components are at ± 600 kHz of the carrier
15 component. The carrier and side band components are illustrated
16 in Fig. 11 and Fig. 12.

17 In one embodiment, the clock for transponder 16 is extracted
18 from the incoming message itself by clock recovery and data recovery
19 circuitry 38. This clock is recovered from the incoming message, and
20 used for timing for microcontroller 34 and all the other clock circuitry
21 on the chip, and also for deriving the transmitter carrier or the
22 subcarrier, depending on whether the transmitter is operating in active
23 mode or backscatter mode.
24

1 In addition to recovering a clock, the clock recovery and data
2 recovery circuit 38 also performs data recovery on valid incoming
3 signals. The valid spread spectrum incoming signal is passed through
4 the spread spectrum processing circuit 40, and the spread spectrum
5 processing circuit 40 extracts the actual ones and zeros of data from
6 the incoming signal. More particularly, the spread spectrum processing
7 circuit 40 takes chips from the spread spectrum signal, and reduces
8 individual thirty-one chip sections down to a bit of one or zero, which
9 is passed to microcontroller 34.

10 Microcontroller 34 includes a serial processor, or I/O facility that
11 receives the bits from spread spectrum processing circuit 40. The
12 microcontroller 34 performs further error correction. More particularly,
13 a modified hamming code is employed, where each eight bits of data
14 is accompanied by five check bits used by the microcontroller 34 for
15 error correction. Microcontroller 34 further includes a memory, and
16 after performing the data correction, microcontroller 34 stores bytes of
17 the data bits in memory. These bytes contain a command sent by the
18 interrogator 26. Microcontroller 34 is configured to respond to the
19 command.

20 For example, interrogator 26 may send a command requesting that
21 any communication device 12 in the field respond with the device's
22 identification number. Status information can also be returned to
23 interrogator 26 from communication devices 12.

1 Communications from interrogator 26 (i.e., forward link
2 communications) and devices 12 (i.e., return link communications) have
3 a similar format. Exemplary communications are discussed below with
4 reference to Fig. 13. More particularly, the forward and reply
5 communications individually include a calibration period, preamble, and
6 Barker or start code which are followed by actual data in the described
7 embodiment. The incoming forward link message and outgoing reply
8 preferably also include a check sum or redundancy code so that
9 transponder 16 or interrogator 26 can confirm receipt of the entire
10 message or reply.

11 Communication devices 12 typically include an identification
12 sequence identifying the particular tag or device 12 sending the reply.
13 Such implements the identification operations of communication
14 system 10.

15 After sending a command, interrogator 26 sends the unmodulated
16 continuous wave signal. Return link data can be Differential Phase
17 Shift Key (DPSK) modulated onto the continuous wave signal using a
18 square wave subcarrier with a frequency of approximately 600 kHz
19 (e.g., 596.1 kHz in one embodiment). A data 0 corresponds to one
20 phase and data 1 corresponds to another, shifted 180 degrees from the
21 first phase.

22 The subcarrier or modulation signal is used to modulate antenna
23 impedance of transponder 16 and generate the modulated continuous
24 wave signal. For a simple dipole, a switch between the two halves of

1 the dipole antenna is opened and closed. When the switch is closed,
2 the antenna becomes the electrical equivalent of a single half-wavelength
3 antenna that reflects a portion of the power being transmitted by the
4 interrogator. When the switch is open, the antenna becomes the
5 electrical equivalent of two quarter-wavelength antennas that reflect very
6 little of the power transmitted by the interrogator. In one embodiment,
7 the dipole antenna is a printed microstrip half wavelength dipole
8 antenna.

9 Referring to Fig. 5, one embodiment of interrogator 26 is
10 illustrated. The depicted interrogator 26 includes a microcontroller 70,
11 a field programmable gate array (FPGA) 72, and RF section 74. In
12 the depicted embodiment, microcontroller 70 comprises a MC68340
13 microcontroller available from Motorola, Inc. FPGA 72 comprises
14 an XC4028 device available from Xilinx, Inc. Further details of
15 components 70, 72, and 74 are described below.

16 RAM 76, EPROM 78 and flash memory 80 are coupled with
17 microcontroller 70 in the depicted embodiment. Microcontroller 70 is
18 configured to access an applications program for controlling the
19 interrogator 26 and interpreting responses from devices 12. The
20 processor of microcontroller 70 is configured to control communication
21 operations with remote communication devices 12 during normal modes
22 of operation. The applications program can also include a library of
23 radio frequency identification device applications or functions. These
24

1 functions effect radio frequency communications between interrogator 26
2 and communication device 12.

3 RF section 74 is configured to handle wireless (e.g., radio
4 frequency) communications with remote communication devices 12.
5 DPSK modulation techniques can be utilized for communications
6 intermediate devices 12 and interrogator 26. RF section 74 can include
7 downconversion circuitry for generating in-phase (I) and quadrature (Q)
8 signals which contain the DPSK modulated subcarrier for application
9 to FPGA 72 during return link communications.

10 Plural antennas, including a transmit antenna X1 and a receive
11 antenna R1 are coupled with RF section 74 for wireless RF
12 communications. Plural RF transmit (TX) ports and RF receive (RX)
13 ports (not shown) are coupled with RF section 74 in a preferred
14 embodiment. Provision of plural TX ports and RX ports enables
15 interrogator 26 to minimize the effects of multipath when communicating
16 with plural remote communication devices 12.

17 Analog to digital converters 82, 84 provide received analog RF
18 signals into a digital format for application to FPGA 72. In particular,
19 analog to digital converters 82, 84 are implemented intermediate
20 FPGA 72 and RF section 74 for both in-phase (I) and quadrature (Q)
21 communication lines. An additional connection 85 is provided
22 intermediate FPGA 72 and RF section 74. Digital signals output
23 from FPGA 72 via connection 85 are converted to RF signals by RF
24 section 74. Connection 85 can be utilized to transmit phase lock

1 loop (PLL) information, antenna diversity selection information and other
2 necessary communication information. During forward link
3 communications, FPGA 72 is configured to format communication packets
4 received from microcontroller 70 into a proper format for application
5 to RF section 74 for communication.

6 FPGA 72 is configured to demodulate return link communications
7 received from remote communication devices 12 via RF section 74.
8 FPGA 72 is configured in the described embodiment to perform I
9 and Q combination operations during receive operations. The
10 described FPGA 74 further includes delay and multiplication circuitry to
11 remove the subcarrier. FPGA 74 can also include bit synchronization
12 circuitry and lock detection circuitry. Data, clock and lock detection
13 signals generated within FPGA 74 are applied to microcontroller 70 for
14 processing in the described embodiment.

15 Microcontroller 70 is configured to control operations of
16 interrogator 26 including outputting of forward link communications and
17 receiving reply link communications. EPROM 78 is configured to store
18 original code and settings selected for the particular application of
19 communication system 10. Flash memory 80 is configured to receive
20 software code updates which may be forwarded to interrogator 26.

21 RAM device 76 is configured to store data during operations of
22 communication system 10. Such data can include information regarding
23 communications with associated remote communication devices 12 and
24 status information of interrogator 26 during normal modes of operation.

1 Referring to Fig. 6, an exemplary embodiment of RF circuitry 74
2 is illustrated. The depicted RF circuitry 74 includes a transmit path 86
3 and a receive path 87. In the depicted embodiment, RF section 74
4 includes a transmitter 90, coupler 91 and power amplifier 92 within
5 transmit data path 86. Receive path 87 includes a receiver 95
6 comprising processing circuitry 96 and an adaptive canceler 97 in the
7 depicted embodiment.

8 Communication paths 86, 87 are coupled with respective
9 antennas X1, R1. Transmit path 86 is additionally coupled with
10 FPGA 72 via connection 85. Receive path 87 is coupled with analog-
11 to-digital converters 82, 84 via the I, and Q connection lines.

12 During communication operations, transmitter 90 is configured to
13 output a radio frequency wireless forward link communication 27 and
14 a radio frequency wireless continuous wave signal using coupler 91 and
15 antenna X1. Further, transmitter 90 is also configured to output a
16 local continuous wave signal using coupler 91. Transmitter 90 is
17 preferably configured to simultaneously output the wireless continuous
18 wave signal using antenna X1, and the local continuous wave signal
19 using coupler 91. The wireless continuous wave signal transmitted via
20 antenna X1 and the local continuous wave signal provided to
21 receiver 95 via coupler 91 have a common frequency (e.g., 2.44 GHz
22 in the described embodiment).

23 Receiver 95 is operable to receive the return link
24 communications 29 from at least one remote communication device 12

1 using antenna R1. As described in detail below, adaptive canceler 97
2 of receiver 95 is configured to receive the local continuous wave signal
3 from coupler 91. Provision of the local signal provides a coherent
4 backscatter interrogator 26 including a coherent transmitter 90 and
5 receiver 95.

6 As previously described, return link communication 29 comprises
7 a modulated radio frequency continuous wave signal in the described
8 embodiment. The modulated signal comprises a carrier signal located
9 at the frequency of the wireless continuous wave signal (e.g., 2.44 GHz),
10 and side bands located at +/- 600 kHz about the frequency of the
11 carrier signal. In the described embodiment, receiver 95 is configured
12 to reduce the power or amplitude of the return link communication.
13 More specifically, receiver 95 is configured to reduce the power or
14 amplitude of the carrier signal of the return link communication.

15 In one embodiment, receiver 95 is operable to reduce the
16 amplitude of the return link communication comprising the modulated
17 continuous wave signal using the local continuous wave signal. More
18 specifically, receiver 95 is configured to reduce the amplitude of the
19 return link communications received by antenna R1 at the common
20 frequency of the continuous wave signals in the described embodiment.

21 As described in detail below, receiver 95 is configured to receive
22 the local continuous wave signal from coupler 91 and adjust the
23 amplitude and phase of the local continuous wave signal. Such
24 adjustment provides an adjusted continuous wave signal. In particular,

1 the amplitude of the local continuous wave signal is adjusted responsive
2 to the amplitude of the modulated continuous wave signal. Preferably,
3 the amplitude of the local continuous wave signal is adjusted to match
4 the amplitude of the received return link communication. The
5 amplitude of the local continuous wave signal is adjusted before
6 adjustment of the phase of the local continuous wave signal in the
7 described embodiment. Following amplitude and phase adjustment,
8 receiver 95 is configured to sum the adjusted continuous wave signal
9 with the modulated continuous wave signal. Thereafter, the summed
10 return link communication having a reduced amplitude at the frequency
11 of the wireless continuous wave signal is applied to processing
12 circuitry 96.

13 Referring to Fig. 7, one embodiment of adaptive canceler 97 is
14 illustrated. Adaptive canceler 97 is configured to reduce the amplitude
15 of return link communications 29. More specifically, during backscatter
16 communications, receive path 87 is susceptible to bleed through of the
17 wireless continuous wave signal transmitted via antenna X1. More
18 specifically, the wireless continuous wave signal communicated via
19 transmit antenna X1 can saturate the front end of receiver 95. This
20 leakage can desensitize receiver 95 and reduce the quality of wireless
21 communications of interrogator 26 with remote communication
22 devices 12.

23 Adaptive canceler 97 utilizes the local continuous wave signal
24 received from transmitter 90 and coupler 91 to reduce the amplitude

1 of the return link communication received by antenna R1 at the
2 frequency of the wireless continuous wave signal transmitted via
3 antenna X1.

4 As previously described, transmitter 90 is configured to output
5 local and wireless continuous wave signals using coupler 91. Initially,
6 the local continuous wave signal is applied to a variable attenuator 105
7 within adaptive canceler 97. In the described embodiment, variable
8 attenuator 105 comprises a voltage controlled attenuator. Variable
9 attenuator 105 is configured to adjust the amplitude of the local
10 continuous wave signal responsive to an external control signal discussed
11 below.

12 Variable attenuator 105 outputs an amplitude adjusted local
13 continuous wave signal. The amplitude adjusted local continuous wave
14 signal is applied to a phase shifter 106. Phase shifter 106 preferably
15 comprises a 360° phase shifter configured to provide an appropriate
16 phase shift of the amplitude adjusted local continuous wave signal.
17 Phase shifter 106 outputs an amplitude and phase adjusted local
18 continuous wave signal which is also referred to as the adjusted
19 continuous wave signal. Phase shifter 106 is controllable via an external
20 control signal described below.

21 The amplitude and phase adjusted local continuous wave signal
22 output from phase shifter 106 is supplied to a power divider 107.
23 Power divider 107 operates to apply the signal to a detector 108 and
24 coupler 109. Detector 108 is operable to measure the amplitude of the

1 adjusted local signal and apply an output signal to an amplitude
2 adjuster 110.

3 Return link communication 29 received via antenna R1 is applied
4 to a coupler 114. Coupler 114 applies the received return link
5 communication 29 to coupler 109 and an amplitude detector 115.
6 Detector 115 is configured to measure the amplitude of the received
7 return link communication 29.

8 Referring to Fig. 8, exemplary embodiments of amplitude
9 adjuster 110 and detectors 108, 115 are illustrated. Detectors 108, 115
10 individually comprise discrete components including diodes, resistors and
11 capacitors. Detectors 108, 115 are configured to measure the amplitude
12 of the respective adjusted continuous wave signal and the modulated
13 continuous wave signal.

14 The measured amplitude values are applied to amplitude
15 adjuster 110 which comprises a feedback amplifier configuration in the
16 depicted embodiment. The illustrated analog implementation of
17 amplitude adjuster 110 is configured to drive variable attenuator 105 to
18 equalize the amplitudes of the adjusted continuous wave signal and the
19 modulated continuous wave signal. Amplitude adjuster 110 is configured
20 to compare the amplitudes of the adjusted continuous wave signal and
21 the received return link communication comprising the modulated
22 continuous wave signal. Thereafter, amplitude adjuster 110 is operable
23 to output a control signal to variable attenuator 105 to match the
24

1 amplitudes of the respective signals. Other configurations of amplitude
2 adjuster 110 are possible.

3 Referring again to Fig. 7, coupler 109 is configured to sum the
4 adjusted continuous wave signal and the received modulated continuous
5 wave signal to reduce the amplitude of the modulated continuous wave
6 signal. The summed continuous wave signal or return link
7 communication is applied to a coupler 118. Coupler 118 is configured
8 to apply the summed signal to low noise amplifier (LNA) 119 and
9 amplitude detector 120. Amplitude detector 120 is configured to
10 measure the amplitude of the summed signal and apply an output signal
11 to a phase adjuster 121.

12 Phase adjuster 121 is controllable responsive to amplitude
13 adjuster 110. Once amplitude adjuster 110 and variable attenuator 105
14 have matched the amplitudes of the adjusted continuous wave signal and
15 the received return link communication, amplitude adjuster indicates the
16 match to phase adjuster 121 via a connection 122. Thereafter, phase
17 adjuster 121 operates to select an appropriate phase shift of the
18 amplitude adjusted local continuous wave signal.

19 In the described embodiment, phase adjuster 121 is configured to
20 search across 360° of possible phase adjustments to detect a phase
21 adjustment of the local continuous wave signal which provides maximum
22 reduction of amplitude of the received modulated continuous wave signal
23 at the continuous wave signal frequency. In particular, adaptive
24 canceler 97 adjusts the phase of the local continuous wave signal

1 following matching of amplitudes of the local continuous wave signal and
2 the received modulated continuous wave signal as indicated via
3 connection 122.

4 Referring to Fig. 9, a graphical illustration of the amplitude of
5 the summed return link communication, represented by reference
6 numeral 136, is illustrated with respect to corresponding plural phase
7 adjustments of the local continuous wave signal. In the depicted
8 illustration, it is shown that a local minimum value 130 corresponds to
9 approximately 150° . For such a situation following searching of 360° ,
10 phase adjuster 121 will apply an appropriate control signal to phase
11 shifter 106 to implement the desired phase shift of approximately 150°
12 to minimize the amplitude of the bleed through of the wireless
13 continuous wave signal within the received return link communication.

14 Referring again to Fig. 7, the summed return link communication
15 is applied to low noise amplifier 119 and processing circuitry 96. Phase
16 adjuster 121 is operable to continuously monitor the amplitude of the
17 summed return link communication and provide appropriate adjustments
18 using control signals applied to phase shifter 106 to minimize the
19 amplitude of the continuous wave signal within the summed return link
20 communication applied to LNA 119.

21 Referring to Fig. 10, exemplary embodiments of amplitude
22 detector 120 and phase adjuster 121 are illustrated. Amplitude
23 detector 120 includes discrete components comprising a diode, resistor
24 and capacitor.

1 Phase adjuster 121 comprises an analog-to-digital converter 124,
2 processor 125 and digital-to-analog converter 126. Processor 125 can be
3 configured to execute appropriate algorithms to implement sequential
4 phase shifts of the local signal from 0° to 360°. The incremental step
5 sizes can be adjusted. Therefore, processor 125 can compare the
6 amplitudes of the summed return link communication signal responsive
7 to various phase adjustments implemented by phase shifter 106.
8 Following selection of an appropriate phase shift, phase adjuster 121 can
9 continue to monitor the amplitude of the summed return link
10 communication and update the phase shift as necessary to maintain
11 maximum reduction of the continuous wave signal within the return link
12 communication during communications. The depicted configurations of
13 detector 120 and phase adjuster 121 are illustrative and other
14 configurations can be utilized.

15 Referring to Fig. 11 and Fig. 12, the received return link
16 communication applied to adaptive canceler 97 and the summed return
17 link communication output from adaptive canceler 97 are illustrated.
18 The received return link communication comprising the modulated
19 continuous wave signal is illustrated as signal 132 in Fig. 11. The
20 summed return link communication is represented by signal 136
21 of Fig. 12.

22 Signal 132 comprises a carrier component 133 and side band
23 components 134. In the described embodiment, carrier 133 is centered
24 at a frequency of 2.44 GHz and subcarrier side band components 134

1 are depicted at locations ± 600 kHz of the carrier component 133.
2 Signal 136 similarly comprises a carrier component 137 and side band
3 components 138. Signal 136 includes carrier component 137 at a
4 frequency of 2.44 GHz and side band components 138 at
5 locations ± 600 kHz of the carrier component 137.

6 As illustrated, the output summed return link communication
7 signal 136 has a carrier component 137 having a reduced amplitude
8 compared with the carrier component 133 of the received return link
9 communication signal 132. Preferably, the amplitude of side band
10 components 138 of summed return link communication signal 136 are
11 maintained during the reduction of amplitude of the carrier
12 component 137 as illustrated in Fig. 11 and Fig. 12.

13 In the depicted illustrations of Fig. 11 and Fig. 12, carrier
14 component 137 of signal 136 is approximately 20 dBm less than carrier
15 component 133 of received return link communication 132. Such
16 indicates the reduction of amplitude of the return link communication
17 signal at the frequency of the wireless continuous wave signal
18 (e.g., 2.44 GHz) utilizing adaptive canceler 97.

19 Referring to Fig. 13, a diagrammatic illustration of forward link
20 communication 27 and return link communication 29 is shown. Initially,
21 forward link communication 27 is communicated using transmit
22 antenna X1 of interrogator 26. Following an intermediate delay or
23 guard band, return link communication 29 corresponding to remote
24 communication device 12 is communicated.

1 Individual return link communications 29 include a calibration
2 period 140 followed by a preamble 141 and actual data 142. Matching
3 of amplitudes of the local continuous wave signal and the received
4 return link communication and cycling through phases from 0 to 360°
5 utilizing phase adjuster 121 and phase shifter 106 preferably occurs
6 during calibration period 140. The minimum level 130 within the
7 summed return link communication signal is preferably determined during
8 calibration period 140.

9 Preamble 141 can be utilized to synchronize the processing
10 circuitry 96 of receiver 95 with the actual return link communication 29
11 being received. Thereafter, data 142 communicated from remote
12 communication device 12 is received. Adaptive canceler 97 is configured
13 to make adjustments as necessary to the amplitude and phase of the
14 local continuous signal during preamble period 141 and data period 142
15 to maintain maximum reduction of the continuous wave signal within the
16 received return link communication 29.

17 Fig. 14 illustrates a variable phase shifter 106 in accordance with
18 one embodiment of the invention. Conventional phase shifters available
19 in the marketplace could be employed; however, these are extremely
20 expensive. The phase shifter 106 illustrated in Fig. 14 is an inexpensive
21 alternative. Additionally, the phase shifter 106 provides phase shifts of
22 anywhere from 0 to 360 degrees.

23 The depicted phase shifter 106 uses a commonly available part
24 known as an IQ upconverter or IQ downconverter 201. The IQ

1 upconverter or IQ downconverter 201 includes a first power divider 200
2 defining an input 210 and having two outputs 212 and 214, a
3 second power divider 208 defining an output 202 and having two
4 inputs 204, 206, and two mixers 216 and 218.

5 The mixer 216 is coupled between the output 212 of the first
6 power divider 208 and the input 204 of the second power divider 200.
7 The mixer 218 is coupled between the output 214 of the first power
8 divider 208 and the input 206 of the second power divider 200.

9 In the described arrangement, first power divider 200 comprises
10 a ninety degree power divider and second power divider 208 comprises
11 a zero degree power divider. Power divider 200 receives an input
12 signal having a phase angle from input 210 which is the amplitude
13 adjusted local continuous wave signal received from variable
14 attenuator 105 previously described.

15 Power divider 200 provides a ninety degree phase shift to the
16 input signal to provide a first component and a second component in
17 accordance with one embodiment of the invention. Inasmuch as power
18 divider 200 provides a ninety degree phase shift, first and second
19 components of the received signal may be referred to as quadrature
20 components. In particular, the first component from output 212 is
21 indicated as a cosine component ($\text{Cos}(\omega t)$) and the second component
22 from output 214 is indicated as a sine component ($\text{Sin}(\omega t)$). The signal
23 components $\text{Cos}(\omega t)$ and $\text{Sin}(\omega t)$ have a sine/cosine relationship as they
24 are shifted ninety degrees from each other. The quadrature signal

1 components shifted ninety degrees apart are applied to respective
2 mixers 216, 218.

3 The depicted phase shifter 106 further includes plural digital-to-
4 analog (D/A) converters 224, 226, I, Q drivers 220, 222, and storage
5 device 228. Phase adjuster 121 is coupled with storage device 228. A
6 second input 203 of phase shifter 106 is provided intermediate phase
7 adjuster 121 and storage device 228.

8 As previously described, phase adjuster 121 is configured to
9 calculate a desired phase shift angle (also referred to herein as Φ) and
10 apply the phase shift angle to storage device 228. More specifically,
11 phase shifter 106 is configured to adjust the phase of the amplitude
12 adjusted local continuous wave signal received from variable
13 attenuator 105 responsive to control signals from phase adjuster 121 and
14 corresponding to the phase shift angle. Appropriate control signals are
15 generated within phase adjuster 121 to indicate the desired phase shift
16 angle for shifting of the phase of the amplitude adjusted local
17 continuous wave signal. In particular, the control signals correspond to
18 the desired phase shift adjustment to provide the local minimum
19 value 130 within the summed return link communication signal as
20 previously described. The control signals identifying the proper phase
21 adjustment are applied to phase shifter 106.

22 Storage device 228 comprises a look-up table in an exemplary
23 embodiment. Such a look-up table may be implemented within
24 an EPROM in one embodiment. Storage device 228 can have one

1 degree resolution, or other resolutions if desired. Storage device 228
2 is configured to store a plurality of sine values and cosine values, also
3 referred to as I and Q digital values. Further, storage device 228 is
4 configured to output one of the stored cosine values and one of the
5 stored sine values to the respective D/A converters 224, 226 responsive
6 to and corresponding to the received phase shift angle determined by
7 phase adjuster 121. For example, if a 45 degree phase shift is desired
8 as indicated from phase adjuster 121, storage device 228 outputs digital
9 look-up table values of 0.707, 0.707 (i.e., cosine and sine of 45 degrees)
10 which are provided to D/A converters 224, 226.

11 Storage device 228 is coupled with D/A converters 224, 226 which
12 in turn are coupled with respective I and Q drivers 220, 222. The
13 cosine and sine digital values outputted from storage device 228 are
14 converted to analog voltages within D/A converters 224, 226. The
15 corresponding analog voltage signals from D/A converters 224, 226 are
16 applied to respective I and Q drivers 220, 222 to implement the proper
17 phase shift within the outputted signal to minimize bleed through.

18 I driver 220 is coupled to mixer 216 and Q driver 222 is coupled
19 to mixer 218 as illustrated. Mixers 216, 218 are configured to scale
20 the respective cosine and sine components of the input signal $\cos(\omega t)$,
21 $\sin(\omega t)$ using the phase shift angle of phase adjuster 121. In the
22 described configuration, mixers 216, 218 individually act as multipliers
23 and multiply the cosine and sine components of the input signal by the
24 respective cosine and sine values from storage device 228 as provided

1 to I and Q drivers 220, 222. More specifically, mixers 216, 218
2 multiply the cosine and sine components $\cos(\omega t)$, $\sin(\omega t)$ of the input
3 signal by voltages outputted by the respective I driver 220 and the Q
4 driver 222 and corresponding to the cosine value and sine value
5 outputted from storage device 228.

6 By adjusting the values outputted by the I driver 220 and the Q
7 driver 222, a phase shift of anywhere between 0 degrees and 360
8 degrees can be obtained. Exemplary phase adjustments are described
9 hereafter. Because the input signal components $\cos(\omega t)$ and $\sin(\omega t)$ are
10 ninety degrees out of phase, if combined at the second power
11 divider 200 comprising a zero degree power divider without use of
12 multipliers 216, 218, the summed components represented as vectors
13 would have the same value as the input signal plus a ninety degree
14 phase shift of the input signal.

15 Assume, for example, that the input signal has a constant phase
16 and an amplitude of 1. If the output signal is desired to have the
17 exact same phase, then the I driver 220 is set to provide one volt to
18 the mixer 216 and the Q driver 222 is set to provide zero volts to the
19 mixer 218. Thus, the signal applied to output 202 would be the same
20 as the signal received from input 210.

21 If a ninety degree phase shift is desired, the I driver 220 would
22 be set to provide zero volts to mixer 216 so there is no signal at
23 output 204, and the Q driver would be set to provide one volt to
24 mixer 218 to produce a ninety degree phase shifted value at the

1 output 202. To produce a 45 degree phase shift, the I driver 220 is
2 set to provide 0.707 volts and the Q driver is set to provide 0.707
3 volts so by vector addition, the signal at the output 202 is shifted 45
4 degrees from the signal at the input 210.

5 Fig. 15 illustrates the relationship between the I and Q signals
6 applied to the mixers 216, 218, respectively. The relationship is a
7 sine/cosine relationship. Appropriate I and Q values may be determined
8 for any other desired degree phase shift (i.e., 0 - 360 degrees). For
9 example, if a 45 degree phase shift is desired (i.e., Φ equals 45
10 degrees), I is at 0.707 (i.e., $\cos \Phi$) while Q is at 0.707 (i.e., $\sin \Phi$)
11 as determined within storage device 228. Such cosine and sine values
12 are provided to the respective I and Q drivers 220, 222.

13 Referring again to Fig. 14, the signals outputted from
14 mixers 216, 218 may be referred to as scaled quadrature cosine and
15 sine components, respectively. The scaled quadrature component from
16 mixer 216 may be indicated as $(\cos(\Phi)\cos(\omega t))$ and the scaled
17 quadrature component from mixer 218 may be indicated as
18 $(\sin(\Phi)\sin(\omega t))$.

19 The scaled quadrature components are applied to second power
20 divider 208. Power divider 208 is configured to combine the first
21 scaled quadrature component received from mixer 216 with the second
22 scaled quadrature component received from mixer 218 to shift the phase
23 angle of the local continuous wave signal by the phase shift angle
24 received from phase adjuster 121.

1 In general, the phase of the signal passing within phase
2 shifter 106 may be represented as $I + Q$ where $I = \cos(\Phi)\cos(\omega t)$
3 and $Q = \sin(\Phi)\sin(\omega t)$. Power divider 208 is configured to add the
4 scaled first and second quadrature components received from
5 mixers 216, 218 to implement phase shifting operations providing the
6 adjusted continuous wave signal at output 202. The adjusted continuous
7 wave signal having a phase angle shifted by the desired phase shift
8 angle Φ is outputted from phase shifter 106 and may be applied via
9 output 202 to power divider 107 and coupler 109.

10 As previously described, coupler 109 is configured to sum the
11 adjusted continuous wave signal and the received modulated continuous
12 wave signal. Such reduces the amplitude of the modulated continuous
13 wave signal at the frequency of the continuous wave to reduce bleed
14 through of the carrier signal.

15 In compliance with the statute, the invention has been described
16 in language more or less specific as to structural and methodical
17 features. It is to be understood, however, that the invention is not
18 limited to the specific features shown and described, since the means
19 herein disclosed comprise preferred forms of putting the invention into
20 effect. The invention is, therefore, claimed in any of its forms or
21 modifications within the proper scope of the appended claims
22 appropriately interpreted in accordance with the doctrine of equivalents.
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